140′+ GBT Spectrometer tests: First Light

Glen Langston and Roger Norrod

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Abstract

First astronomical observations with the GBT spectrometer are presented. Emission from two astronomical sources are shown here, *1)* the bright water maser in the Orion Nebula and *2)* a fainter hydrogen recombination line toward the galactic center, in Sagittarius B 2 (SGR-B2). The spectrometer is shown to function well in one test mode. Further work is needed to check observing modes and understand the properties of the band pass.

1 Observations

The first observations of the Orion Nebula with the GBT spectrometer were made on 98 May 22 (day of year 141). Observations of SGR-B2 were made on 98 May 24. These observations used the 140′ with the K band receiver designed by Mike Stennes, and built by Tom Dunbrack. The K band receiver is a GBT receiver currently installed in the Cassegrain house on the 140′ . The receiver was installed in the normal manner. Dana Balser provided extensive help with the 140′ setup and checkout. The K band pointing and focus were also checked in the normal manner. Wes Grammer and Gary Anderson helped confirm the proper functioning of the IF chain, which was input to the detectors for pointing and the auto-correlator.

Both Orion and the SGR-B2 region were observed using a procedure called "MFOC", which modulates the focus of the receiver at 1 minute intervals. During the observations, the receiver is moved up and down by an 1/8 of a wavelength in order to reduce the time average of the standing waves. The spectra shown below were produced from the difference of the average of observations ON-source and OFF-source. The OFF-source position was set to 8 arc minutes west of the source location.

The GBT software does not currently support detailed logging of the state of the spectrometer and its IF inputs. There were no computer logs of the times of observations and the hardware settings. However this problem was overcome by Keri Eberhardt, who made careful notes of the times of observations.

2 RF Down Conversion

For the observation of the water line, the first down conversion was done with a fixed oscillator at $0.340 \times 4 \times 12 + 0.8$ GHz $= 17.12$ GHz. This places the water line (22.235 GHz) at 5.115 GHz, within GBT fiber optic modem IF input band. The IF signal is split and one output is provided to the fiber optic transmitter and the other was input to a series of mixer stages which end in the 140′ control room. The fiber optic transmitter is located in the 140′ Cassegrain house. The fiber optic receiver is located in the GBT equipment room, on the second floor of the Jansky Lab new wing. The output of the receiver was fed into channels one and two of the GBT converter rack. The GBT converter module contains a variable frequency up-conversion (LO2) into the 8.5 to 10.35 GHz band pass filter, followed by a fixed down conversion by 10.5 GHz. For the Orion observation, LO2 was set to 14.415 GHz.

During these tests, the auto-correlator at the 140′ was used to confirm proper system setup. Spectra of the emission from these sources were also produced using the auto-correlator.

For the SGR-B2 observation, the first down conversion was done with a fixed oscillator at $0.315 \times 4 \times 12 + 0.8$ GHz $= 15.92$ GHz. This down conversion placed the $H_\alpha 68$ line (at 20.642 GHz) at IF frequency 4.722 GHz, within the 2 to 6 GHz pass band accepted by the fiber optic modem. The LO2 setting was 13.942 GHz. The final down conversion results in the line appearing at 1.1 GHz at the input to the spectrometer wide band sampler.

The 1-8 GHz converter module was used to adjust the signal level to the value required at the spectrometer wide band sampler. From the 1-8 GHz converter module the signal was provided to the Analog Filter Rack, were it is filtered then routed to the spectrometer wide band sampler. The filter module was configured to use the 0.8 to 1.6 MHz band pass filter.

Roger Norrod, Mike Stennes and Rich Lacasse tested the RF input signals in advance of the test, produced a test fixture for the spectrometer inputs and made adjustments to provide correct levels to the spectrometer sampler. Test tones were transmitted from the Jansky Lab toward the 140′ and were detected through the receiver chain to confirm proper operation.

The IF electronics modules in the GBT equipment room were configured using Glish interface screens written by Ron Maddalena and Roger Norrod. This software was based on version 2.7 of the Monitor/Control Software.

3 Spectrometer Setup

The GBT spectrometer was designed by Ray Escoffier. Ray and Jeff Hagen had previously tested the spectrometer operation many of its observing modes. Unfortunately only the internal switching modes had been tested at the time of these observations.

Roger Norrod, Mike Stennes and Rich Lacasse set up and tested the external switching inputs to the spectrometer. They made a large number of detailed tests of the RF and logic signals to the spectrometer inputs before these observations. The logic signals were intended to synchronize the detection of cal signal and to distinguish antenna nutator ON-source/OFF-source states.

The observations presented here used only the internal timing references of the spectrometer. These were the modes most fully tested by Ray and Jeff. For these tests, all data was averaged for 5 seconds then written to disk in binary format (not FITS). The file names were used to time-tag the data. We kept paper notes of when the antenna was on and off source.

The cal signal was switched at a 1 Hz rate, so both cal on and cal off states are averaged. No

Molecular Line	Rest Frequency (MHz)	First IF Frequency (MHz)	Second IF Frequency (MHz)
H_2O	22235.080	17120	14415
$He_\alpha 68$	20470.110	15920	13942
$H_\alpha 68$	20461.658	15920	13942

Table 1: Frequencies of lines observed in the Orion and SGR-B2 regions

absolute calibration of the spectra amplitude is possible.

The configuration of the spectrometer was done using Jeff Hagen's program **spec**. The spectrometer was set up to produce a 4096 channel spectrum for only one IF channel (RCP from 140′). The wide band sampler was used to produce the 800 MHz bandwidth spectra. The 100 MHz samplers were not used for this test.

After the first tests of the spectrometer using the single spectrum mode, we attempted to use the external cal on/off and ON-source/OFF-source signals. These signals were used to extract 4 spectra corresponding to each of the four possible states of the input signals. Unfortunately the four spectra had peculiar shapes suggesting either an input problem or a problem in reading the four spectra from the spectrometer. These results were discarded. (On 98 May 28, Ray Escoffier and Jeff Hagen discovered a timing problem at the interface between the VME computer and the spectrometer. A simple fix was added by Jeff Hagen and these tests showed that the spectrometer appeared to function correctly when synchronized to the external timing signals. These tests are the subject of a separate memo.)

All of the results presented here use only the GBT spectrometer internal timing logic for selecting the data for averaging and output.

4 Data Reduction

The raw data were written to disk in a binary format devised by Jeff Hagen. Glen Langston wrote a program (**specSum**) to distinguish between the ON source and OFF source data and produce data averages for ON and OFF. The program also produces the final spectrum by subtracting the OFF source from the ON source data. The calibration of the frequency axis of the spectrum was done by retrieving the LO settings from paper notes and inputing the values to the conversion program.

No attempt was made to "band-pass" calibrate the variable gain across the spectrum. It was noticed that the noise level decreased with decreasing spectral power, indicating that there was only a gain variation, not a sensitivity variation, across the band.

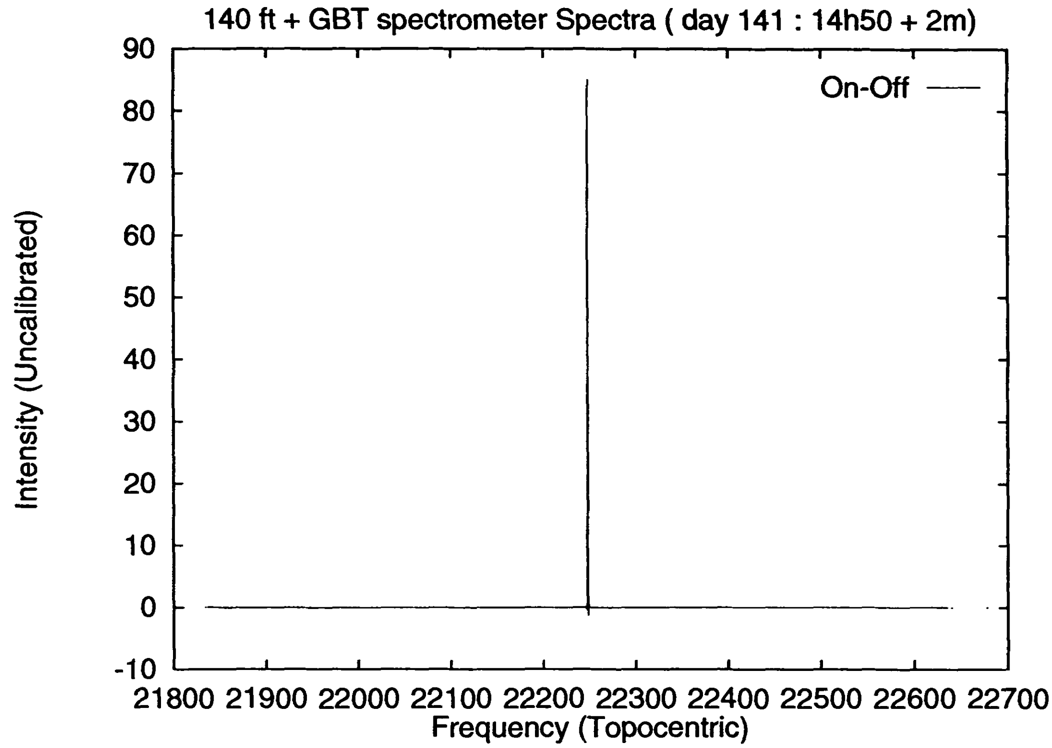

Figure 1: First light on the GBT spectrometer. Observations of the water maser in the Orion Nebula

5 Orion Nebula

The result of this program for the Orion observation is shown in Figure 1. Data from this observation were taken on 98 May 22 between 19h53m and 19h57m UTC. The water line is located in the center of the plot. There are some numerical problems associated with observations of the very bright feature in the spectrum. This causes "ringing" in the channels near the line. This effect is also seen when observing the water line with the auto-correlator at the 140′ .

For the Orion observation presented here, the total integration time was 2 minutes on source and two minutes off source.

6 SGR-B2

The H_α 64 recombination line in the SGR-B2 region is a reasonable test target for the spectrometer, due to the moderate brightness of the line. Observations with the auto-correlator show the line to be approximately 0.5 K, which is small compared to the 100 K system temperature at the time of the observation. The observing cycle was 4 minutes 40 seconds of observation at a position 8 arc-minutes offset the SGR-B2 region, followed by 4 minutes 40 seconds on SGR-B2. This cycle was repeated twice. The observations were made on 98 May 24 between 5h47m39s and 6h06m10s UTC.

Figure 2 shows the spectrum containing the H_α68 line, which is clearly visible in the center of this plot. The entire 800 MHz spectrum is shown in figure 3. The X axis of the plot is the sky frequency (topocentric) in MHz, without any corrections for the motion of the observer (ie. the Earth) relative to the source.

The plots of the same SGR-B2 spectra shown in figures 2 and 3 are the result of very small differences between the ON and OFF observations. The separate ON and OFF spectra are shown in figure 4. The spectrum at the bottom of figure 4 is the same data as that shown in figure 3.

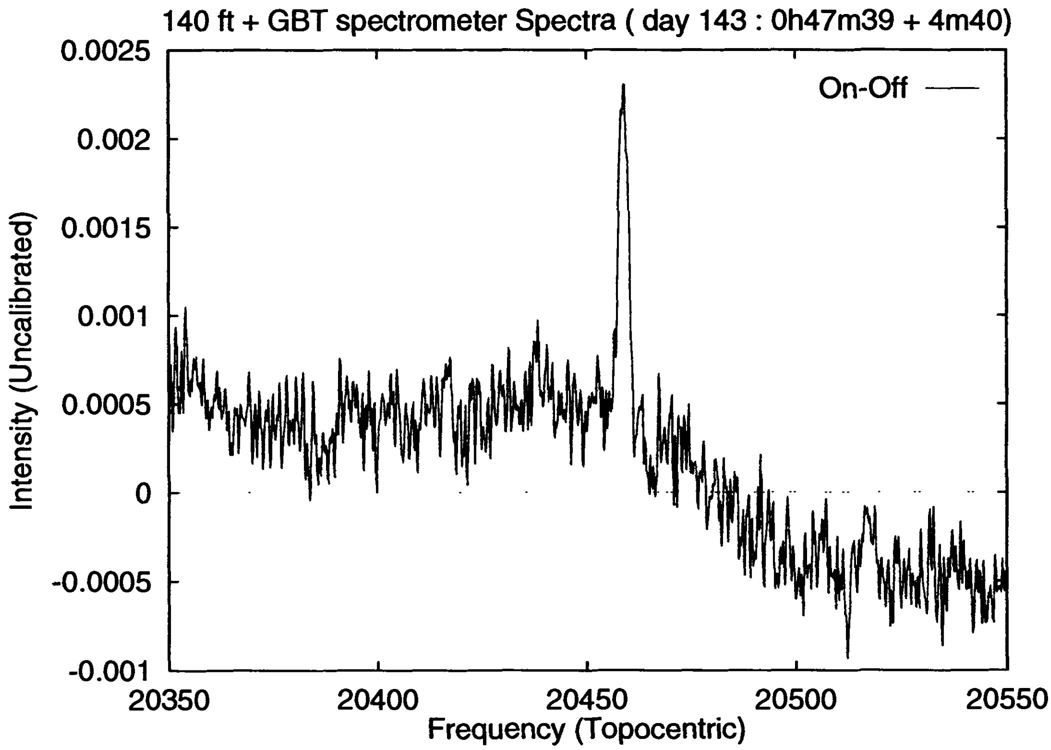

Figure 2: 200 MHz section of GBT Spectrometer output

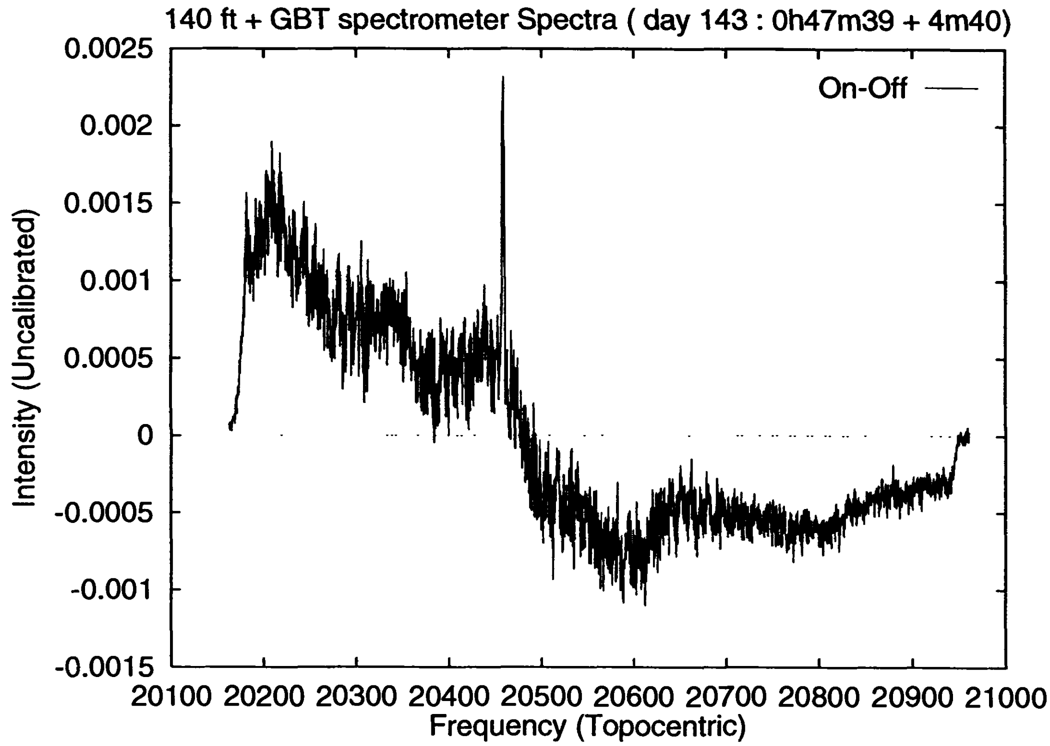

Figure 3: Entire 800 MHz GBT Spectrometer output

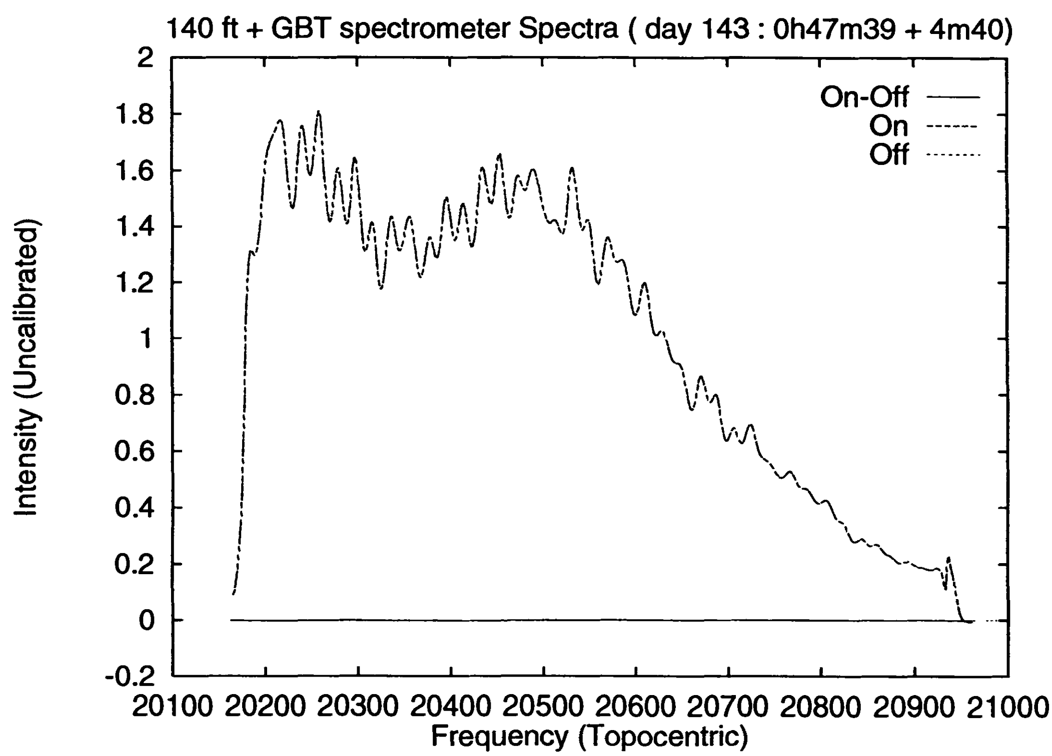

Figure 4: Comparison of the ON and OFF spectra used to produce the spectra in figures 2 and 3.

The overall spectral shape in figure 4 is due to the varying gain of the K band receiver over this frequency range. Note that the ON and OFF spectra are nearly identical in the figure 4. In order to calibrate the intensity scale for the spectra, the CAL-ON and CAL-OFF signals must be separately detected. This was not possible at the time of these observations.

7 Summary

The GBT spectrometer was successfully tested in one of its data processing modes. Major portions of the GBT IF system were used during the experiment, including the following equipment:

A: K Band Receiver

B: RF optical transmitter and optical fiber

C: RF optical receiver

D: 1-8 GHz converter modules with associated local oscillators

E: Sampler/Filter Modules

F: Synchronization signals transmitted via fiber optic modem

Several additional tests are needed. Rick Fisher has produced a detailed plan for testing the GBT spectrometer, and a few of those points are highlighted below:

1 Fully test the synchronization of spectrometer with external cal ON/OFF and signal/reference signals, which is critical for observations of faint sources.

2 Careful study of effects of IF filters in the system are needed, in order to calibrate the relative sensitivity of these observations over the wide bandwidth.

3 The 140′ auto-correlator was used to confirm the proper LO settings and antenna pointing. During the observations, a number of problems were found with the auto-correlator itself. All of these problems could have been detected in advance if there was a well documented test fixture and procedure for the auto-correlator. For the GBT, a test fixture is needed that allows synchronous detection of the CAL signal and also produces a line in the test spectrum. This would prevent loss of time in diagnosing spectrometer problems.

4 The CAL signal level is known to vary over the wide bandwidth, and a more detailed CAL signal model will be required.

5 Some of our observations with the GBT spectrometer were lost due to failures to log the state of the input to the spectrometer. Software to periodically log a complete description of the state of the equipment would have been helpful.

Without the support of most of the Green Bank staff, this test would not have been possible. Fortunately the results of this tests are very positive, and after some additional work, the GBT spectrometer should produce very valuable scientific results.